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SAFEGUARDS AND SECURITY ISSUES FOR THE U.S. FISSILE MATERIALS DISPOSITION PROGRAM

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ABSTRACT

The Department of Energy's Office of Materials Disposition (MD) is analyzing long-term storage and disposition options for fissile materials, preparing a Programmatic Environmental Impact Statement (PEIS), preparing for a Record of Decision (ROD) regarding this material, and conducting other related activities. A primary objective of this program is to support U.S. nonproliferation policy by reducing major security risks. Particular areas of concern are the acquisition of this material by unauthorized persons and preventing the reintroduction of the material for use in weapons. This paper presents some of the issues, definitions, and assumptions addressed by the Safeguards and Security Project Team in support of the Fissile Materials Disposition Program (FMDP). The discussion also includes some preliminary ideas regarding safeguards and security criteria that are applicable to the screening of disposition options.

BACKGROUND AND INTRODUCTION

At the request of the Presidential National Security Advisor and sponsored by the Department of Energy (DOE), the National Academy of Sciences (NAS) conducted a study of the options for achieving long-term disposition of the excess plutonium from nuclear weapon dismantlement. The NAS published their report in 1994, entitled "Management of Disposition of Excess Weapons Plutonium."

The NAS report recommended that the U.S. and Russia pursue long-term plutonium options that:

1. minimize the time during which plutonium is stored in weapons-usable forms;
2. preserve high standards of safeguards and security during any disposition process;
3. result in a form from which recovery would be difficult; and
4. meet high standards of protection for public and worker health and for the environment.

The DOE has established a program, Fissile Materials Disposition Program (FMDP), to address the disposition options applicable to the long-term storage and disposition of surplus fissile material. Within this program, a project has been defined to focus on the safeguards and security needs of the various long-term storage and disposition options being considered.

The safeguards and security activities are an important cross-cutting task that must be addressed for all of the FMDP options. There are two distinct areas that will be considered for each facility/technology option: domestic safeguards and security, and international safeguards. Two sub-elements traditionally make up domestic safeguards and security: nuclear materials control and accounting, and physical protection required for the protection of nuclear materials against threats of theft, diversion, and radiological sabotage. Likewise, international safeguards traditionally consists of two sub-elements: nuclear materials accountancy, and material containment and surveillance. FMDP facilities, unlike many U.S. facilities in the past, will be subject to domestic and international safeguards. Developing and implementing these systems for the FMDP will pose major challenges in the areas of technology and international material protection practices.
The commitment to place material under the safeguards of the International Atomic Energy Association (IAEA) poses a new precedence for the U.S. In the sections that follow, we discuss some proliferation resistance issues and present some of the criteria that could be used to sort through the various options.

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IAEA POLICY ASSUMPTION

In his speech to the United Nations in September 1993, President Clinton stated, "...the U.S. will...submit U.S. fissile material no longer needed for our deterrent to inspection by the International Atomic Energy Agency" (Nonproliferation and Export Control Policy, the White House Fact Sheet dated September 27, 1993). It is, therefore, logical to assume that all the surplus material considered for disposition could end up on the Voluntary Offer that the U.S. provides to the IAEA; to do otherwise would be contrary to the U.S. nonproliferation objectives.

Accommodating international accountability of declared-surplus fissile material is consistent with the Nonproliferation and Export Control Policy of the U.S. To provide for this accountability and minimize proliferation risks, we are assuming that all DOE weapons-usable fissile materials declared surplus to national security needs will be made available for IAEA safeguards. To achieve consistency among all long-term storage and disposition options being considered in the DOE Fissile Materials Disposition Program, the following specific *assumptions* will be made:

a) Any material already under IAEA safeguards will remain under IAEA safeguards.

b) Any material not under IAEA safeguards will, for the purposes of uniformity of data treatment for the Programmatic Environmental Impact Statement (PEIS) and Record of Decision (ROD), be treated consistent with IAEA safeguards, when in fact it may not yet be under IAEA safeguards.

c) Any fissile material not declared surplus to stockpile and the strategic reserve will be exempt from IAEA safeguards.

PROLIFERATION RESISTANCE

The 1994 NAS study stated that, "The primary goal in choosing options for the management and disposition of excess weapons fissile materials should be to minimize the risks to national and international security." The NAS divides this goal into three objectives: 1) reducing the risk of proliferation by unauthorized parties, 2) reducing the risk of reintroduction of the materials into the arsenals from which they came, and 3) strengthening national and international control of fissile materials. The NAS study also recognized the importance of considering the proliferation resistance inherent in all phases of disposition from the current state of the materials through processing to final disposal. In addition, the study considered the implications of U.S. excess weapons materials disposition as a model for the ultimate disposition of fissile materials. This study considered both weapons and commercial fuel cycles worldwide, recognizing that each country will view disposition options in the context of their specific fuel-cycle plans.

Consistent with this broad view of proliferation resistance, criteria for evaluating proliferation resistance of plutonium disposition options are being developed that 1) encompass all stages of disposition from storage through intermediate processing to final disposition, and 2) consider the varying safeguards environment.

COMPONENTS OF PROLIFERATION RESISTANCE

The proliferation resistance of a disposition option is determined by the material form, the physical environment afforded by the technology/facility that processes or stores the material, and the level of safeguards and security that are applied to the material. All of these factors affect the resources and technical complexity for acquiring, transporting, and processing the material for use in a nuclear explosive. Because any disposition option is a time-variant path from the current state of the material to the final disposition state, the total proliferation resistance is a function of the proliferation resistance at each stage.

Material Form

Key in the NAS description of the spent fuel standard (SFS) is the word *inaccessible*. Because the material is large, radioactive, and chemically unattractive, plutonium in spent fuel is inaccessible. The form of the material reflects its properties, both intrinsic and extrinsic. The form of the material in terms of its radiological, chemical, and physical characteristics affects the difficulty of acquiring the material and processing it for use in a nuclear explosive. Materials such as spent fuel that are highly radioactive cannot be handled directly, requiring instead shielding and remotely operated equipment to avoid lethal radiation doses. This increases the technical complexity of both the acquisition and processing of these materials.

The technical complexity of the material and the time required to process it into a form usable in a nuclear explosive are dependent on the chemical form. Materials such as plutonium metals and oxides require limited or no processing. On the other hand, low concentrations of plutonium in spent fuel or other waste forms require more complex processing equipment. They also require longer times to separate fission products and other matrix materials to obtain sufficient quantity of plutonium for a nuclear explosive.

Physical form, especially size and weight, affects proliferation resistance in terms of the difficulty of moving the material to a location where it can be processed. For example, plutonium in the form of containers of oxide powder is readily transportable, whereas plutonium in a light-water reactor spent fuel assembly requires special equipment for lifting, handling, and transport.

The Spent Fuel Standard

The term *spent fuel standard* was coined by the NAS in their 1994 report. In discussing plutonium disposition, they stated, "We believe that options for the long-term disposition of weapons plutonium should seek to meet a 'spent fuel standard' -- that is, to make this plutonium roughly as inaccessible for weapons use as the much larger and growing quantity of plutonium that exists in spent fuel from commercial reactors." It was their clear intent that surplus plutonium would be rendered at least as proliferation-resistant as the plutonium in existing commercial spent fuel. However, SFS was not clearly defined since they did not identify "inaccessibility" or what characteristics made the material inaccessible. The ambiguity of the term *spent fuel standard* is exacerbated by the inclusion of the term *standard,* which itself has a multiplicity of meanings.

With this in mind and prepared to address proliferation resistance and the relationship to the SFS, it became clear that a more formal definition of the SFS was required to ensure that the term SFS is applied consistently within the program. We have defined the following characteristics or properties that must exist to effect the SFS material form for plutonium-laden materials.

Characteristics of the Spent Fuel Standard

The SFS described here consists of four parts. These include the radiological, physical, chemical, and nuclear properties of the material form that make any residual surplus plutonium as inaccessible for recovery as the plutonium in commercial spent fuel. Three of the characteristics (radiological, physical, and chemical) directly influence the particular requirements, regulations, and practices for the application of safeguards and security, for both domestic and international purposes. Therefore, material *needs to meet all three characteristics* in order to satisfy the *spent fuel standard.* The nuclear properties of the plutonium (isotopic composition) were not considered a discriminating factor for proliferation risk and are not considered further in this paper.

Radiological Properties

Currently, both the DOE and Nuclear Regulatory Commission (NRC) regulations allow reduced safeguards and security practices if the radiation level of the material exceeds a certain high-level dose rate. The proliferation-resistance benefit of the spent fuel standard is engendered by the very high radiation field strengths associated with Pu-laden materials. The dose rate is high enough to be disabling or lethal to humans without specialized shielding equipment who may approach the material and remain in its vicinity long enough to effectively divert or recover the plutonium from the material. While the radiation level declines with time, significant levels of radioactivity are persistent and remain effective for 30 to 50 years. However, once the dose rate falls below the allowed limit, then more stringent safeguards and security measures must be implemented. Because specialized equipment is needed for diversion and recovery operations, the level of effort and the quantity of resources are greatly increased during all phases of recovery operations until the radioactivity is isolated from the surplus plutonium.

The NRC and the DOE consider special nuclear materials (SNM) emitting more than 100 rad/hour at 1 meter to be sufficiently self-protecting to require a lower level of safeguards. The justification for this reasoning is that levels of radiation of this magnitude are large enough to cause severe illness to an individual after only a few hours of exposure and a high probability of death in 2 - 6 hours of exposure. Typical biological effects of whole-body doses are well documented.

Physical Properties

Large bulky and heavy items facilitate the implementation of safeguards and security measures, both from domestic and international standpoints. Domestically, theft-detection capabilities are significantly enhanced by large physical properties (size and weight) because movement of the material is detected more readily. Also, the need to use heavy equipment to remove the material (as in the case of theft) gives the response force more time to react. Internationally, large items facilitate item accountancy, as well as detection of item movement using containment and surveillance measures. It should be noted that the containment and surveillance requirements that must be followed for large and bulky items are no different than those specified for small and light-weight items. However, it is generally easier to implement protection elements for larger items. For spent fuel the nuclear material is packaged in strong and robust assemblies.

Chemical Properties

The chemical properties of the nuclear material also impact the domestic safeguards and security requirements. The extent of the processing required to convert nuclear materials to a nuclear explosive device determines the attractiveness of the material. That attractiveness subsequently determines the level of safeguards and security that must be provided to quantities of material. Both U.S. (DOE Order 5633.3B) and IAEA (INFCIRC 254, 274) categorize nuclear material.

The proliferation resistance benefit for the spent fuel standard is engendered in the chemical properties of the material that make it more difficult to recover plutonium from adjoining materials. An essential chemical property for the spent fuel standard is the plutonium content in residual plutonium shall be **dilute** and substantially **homogeneously** dispersed in a **solid** matrix which is enclosed in a sealed package.

Physical Environment

Ease of access to material depends on the number and kinds of barriers surrounding the material locations and the extent to which penetrations in these barriers are sealed or controlled. Clearly, those facilities with limited or no access to material by workers provide greater barriers to the material. For example, material temporarily stored in a receiving area is more accessible than material in long-term storage in a vault or in a geologic repository. Modern automated processing facilities provide greater inherent protection than older facilities (that require hands-on access through glove boxes) by minimizing personnel access to material. On the other hand, while automation contributes to proliferation resistance for the contained materials, the remoteness of the material complicates some aspects of the material accounting safeguards.

Safeguards and Security

As mentioned earlier safeguards and security includes both domestic and international safeguards. Domestic safeguards generally consist of material control and accounting as well as physical protection measures with the goal of detecting and interrupting unauthorized attempts to access nuclear materials. International safeguards consist of verifying a state's system of accounting using material accounting methods complemented by containment and surveillance. The international safeguards regime does not have the role of protecting materials; instead, it confirms the correctness of the state's declarations.

The DOE, the NRC, and the IAEA have developed criteria for evaluating the relative attractiveness of nuclear materials for use in nuclear explosives devices. These criteria determine a graded safeguards approach wherein materials that are most readily used for nuclear explosives purposes are assigned increased safeguards. The criteria are generally related to the amount of the material required for a single weapon (significant quantity), the time to process the material to a weapons-usable form, and the technical difficulty of processing to this form.

The DOE assigns attractiveness levels to the various forms of plutonium which reflect the relative ease of processing and handling required to convert that material to a nuclear explosive devices. These levels in order of decreasing attractiveness are: 1) assembled weapons and test devices; 2) directly convertible materials such as pits, buttons, and ingots; 3) high-grade materials such as oxides, carbides, and nitrates; 4) low-grade materials such as process residues; and 5) highly irradiated forms. A graded safeguards approach is applied with the higher attractiveness levels and larger material amounts receiving more stringent materials accounting and physical protection. The highest level of protection is applied to attractiveness Level A materials in amounts of 2 kg or more. The lowest level of protection is applied to attractiveness E which includes irradiated forms such as spent fuel.

The NRC also applies a graded approach to material accounting and physical protection with more stringent measures applied to increasing amounts of plutonium. Amounts of plutonium in excess of 2 kg receive the strongest protection measures. However, for plutonium in self-protecting material, defined as radioactive material with a total external radiation dose rate in excess of 100 rems per hour at 3 feet, the material accounting and physical protection requirements are reduced.

The IAEA defines a significant quantity of plutonium as 8 kg and prescribes material accounting and containment/surveillance measures according to the attractiveness of the material.. The attractiveness criteria consider difficulty of processing the material and the time to process. The safeguards must meet timeliness and detection probability goals based on the material form. The loss of a significant quantity of plutonium in separated form must be detected with high probability within 1 month. The loss of a significant quantity of plutonium in spent fuel must be detected with high probability within 3 months.

Material form, physical environment, and safeguards are interrelated with variations in one component affecting the proliferation resistance of the others. Indeed, these components of proliferation resistance may sometimes be in conflict such that increases in the proliferation resistance of one component decreases the effectiveness or increases the cost of another component. For example, materials in item form are more readily safeguarded than materials in bulk form where measurement uncertainties complicate precise accounting for the material; restrictions on physical access lower the threat of theft while limiting the ability to confirm continued material presence; and material forms that are radioactive improve the self-protection of the materials while complicating the problem of measuring the material. These criteria suggest that selection of a disposition option should include an examination of the trade-offs between all of the proliferation risk components.

FACTORS AFFECTING THE TECHNICAL DIFFICULTY OF ACQUIRING MATERIAL

The following are proposed as proliferation resistance measures in the fissile materials disposition process. The specific measures have not been decided upon and further refinement is continuing.

Physical Environment

The physical location of the material can affect its accessibility to a proliferator. Barriers (i.e., natural, facility, or process equipment) are all factors in determining ease of access. For example, spent fuel in a geologic repository is clearly less accessible than spent fuel in a pond.

Safeguards/Physical Protection

The detection and prevention of an access attempt depends on the levels of safeguards and physical protection at the facility. In general, safeguards are more easily applied and more readily verified when materials are in the form of discrete, uniquely identifiable items (such as PuO_2 in sealed containers) as opposed to materials in bulk form in a chemical processing facility.

Self Protection Aspects of the Material

A material's characteristics can complicate gaining physical control of a significant quantity of the material. For example, radioactivity of spent fuel increases the technical complexity of acquiring the material.

Physical Form

A material's size and weight increase the technical complexity of its transport to a location where it can be processed. Clearly, a spent fuel assembly is more difficult to transport than a container of separated plutonium.

FACTORS AFFECTING THE DIFFICULTY OF PROCESSING THE MATERIAL

Technical Difficulty of Processing

The technical complexity of recovering a significant quantity of the material through chemical reprocessing, isotopic enrichment, etc., is a measure of the difficulty of processing the material.

Time of Processing

The time to recover a significant quantity will depend on the available technology, the initial form of the material, chemical processes, and the amount of material that must be processed to achieve a significant quantity. Clearly, materials having a low concentration of plutonium will require longer processing times.

USING CRITERIA FOR EVALUATING DISPOSITION OPTIONS

Safeguards and security is critical in the evaluation of a number of criteria to be used for the ROD, in particular the criteria of resistance to theft or diversion by unauthorized parties and the criteria of resistance to retrieval, extraction and reuse by a host nation. To determine the best option, it may take more than defining the proliferation resistance characteristics of the material being considered. Thus, we addressed elements or criteria to be applied for screening options based on effecting preferred safeguards and security characteristics. The criteria should measure the inherent value of the option. If some standard must be met, then all options should include (in their cost) the amount necessary to meet the standard as a separate item.

In the previous section, we mentioned that proliferation resistance was a function of the elements of *material form*, the *physical environment* the material is in, and *safeguards and security.* Each of these elements contribute in some way to the ultimate proliferation resistance.

For purposes of defining criteria, *material form* can also be thought of as nuclear material attractiveness to diversion or theft, where *attractiveness* can be taken from attractiveness levels as defined in DOE Order 5633.3B. A second factor for material form is the *time* the material exists in the particular state of the process being considered.

The attractiveness of the nuclear material takes into account the form, radiation barriers, ease of separation, and ease of use in a nuclear device.

The environment can refer to the *nature of the process step* in terms of accessibility of, or resistance to, removal. The global process steps are thought of broadly as transportation of material, processing of material in a plant, and storage of material in a facility. Again, the second factor for environment is the *time* the material exists in the particular state of the process being considered.

Finally, the safeguards and security characterization element can depend on a number of different factors: the *number of hand-offs or transfers* of material (i.e., concern with the number of individual steps which might occur within a specific activity where there is access to the material); the *ease of implementing safeguards and security* material control and accountability (i.e., whether item or bulk accountability will be used); *international inspectability* (i.e., the feasibility of implementing the international inspectorate protocol determined by whether the material is in a classified form, non-IAEA inspectable; or in an unclassified form, IAEA inspectable).

In the above, a *step* refers to an entity associated with handling or processing the material, as shown in the example discussed below.

With the above parameters and relationships defined, the parameters could be scored so that a higher score indicates the more attractive proliferation target (i.e., higher is worse). For example, a value of 1 could be assigned for *time in step* of one week or less, while a weighted value of 5 could be assigned for *time in step* of one week to three months. Weighted values could similarly be assigned for the *level of attractiveness, the nature of the step,* etc. Having these values, one can then define options and scenarios, assign weighted values for each of the equation elements, and yield a comparison of the options for their inherent attributes of proliferation resistance.

It is likely that some adjustment to the weighting values might be necessary to ensure that the results are reasonable. At this time, we are working to establish the proper method of weighting different options for their safeguards and security attributes. There is no doubt this process will continue to evolve into something more representative and appropriate for screening the best options. The formal presentation at the conference will present up-to-date developments on this process.

SUMMARY

In summary, an important aspect of the U.S. Fissile Materials Disposition Program is effective protection of weapons-usable fissile material. Since one of the program objectives is to preserve high standards of safeguards and security during any disposition process and end with a disposition result in a form that would make recovery difficult, safeguards and security continues to be a major element in the process of selecting the most practical options for the long run. Adding to the complexity of the disposition process is the fact that the U.S. has committed to submit (for inspection by the IAEA) U.S. fissile material no longer needed for our deterrent. This paper discusses some of the assumptions made for this program to satisfy the IAEA commitment. Addressing the issues of safeguards and security for this program means looking at several variables that focus on proliferation resistance. There are numerous factors to consider in defining this issue. We have addressed some of the variables that we are considering in the process of defining proliferation resistance and protection of nuclear material in general.

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